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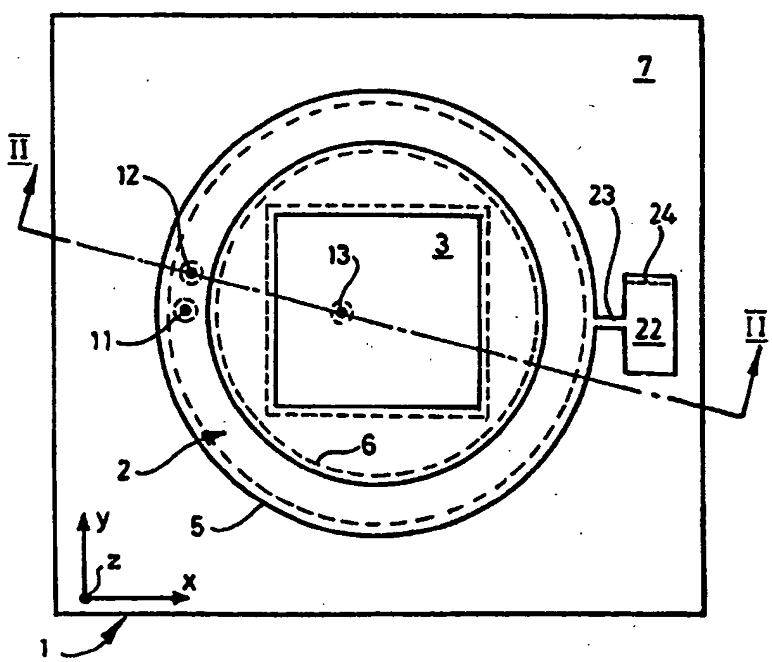
(54) Title: ANTENNA UNIT

(57) Abstract

The present invention relates to an antenna unit, and in particular to a low profile antenna unit which provides dual band operation for reception and/or transmission for both terrestrial and earth-orbiting satellite radio communication. The antenna unit (1, 31, 51, 81, 101) has substantially planar conducting sections in close proximity, the sections defining at least one ground plane (4, 34, 35, 59, 83, 103), a first radiator (3, 34, 52, 80, 100) with a response pattern extending in an elevation plane for satellite communications, and a second radiator (2, 32, 53, 82, 102) with a response pattern extending in an azimuthal plane for terrestrial communications. The second radiator is adapted for radio communication with radio signals having an electric field polarised substantially in an elevation plane, and the radiators preferably share a common ground plane. In one embodiment, the first and second radiators are respectively a patch radiator (3, 34, 52) and a slot radiator (2, 32, 53). In another embodiment, the radiators are respectively a patch radiator (80, 100) and a bent folded monopole radiator (82, 102).



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Antenna Unit

The present invention relates to an antenna unit, and in particular to a low profile antenna unit which provides dual band operation for reception and/or transmission for both terrestrial and earth-orbiting satellite radio communication.

Radio transmitters and receivers, or communication units, for terrestrial radio communication are commonly used in many applications such as mobile telephones in motor vehicles, ship-to-shore communications, and hand-portable personal pagers. In some applications the transmitter and/or receiver is fixed, and in others mobile.

These communications systems commonly operate in the 400 MHz, 900 MHz and 1.7 GHz parts of the radio spectrum, and use antenna units which are usually vertically oriented and are usually multiples of one-quarter wavelength ($\lambda_0/4$) long, where λ_0 is the free-space wavelength of the signal. These vertical rod $\lambda_0/4$ antennas, with a $\lambda_0/4$ image provided by a ground plane, efficiently receive and transmit with a substantially omnidirectional antenna response pattern in the azimuthal plane to a signal with a vertically oriented electric field. The term "vertically oriented electric field" as used herein means an E-field either polarised or with substantial components transverse to the azimuthal plane. Such an antenna unit is well-suited to applications such as mobile cellular radio communication, but is exposed and may be prone to damage, for example if mounted on a motor vehicle.

Another type of antenna unit for use on a motor vehicle, and with a much lower profile, is disclosed in the document GB 1387679, which describes an antenna, which operates in a mode referred to herein as a "slot" mode.

This antenna is a planar slot-ring of conducting material on a substrate mounted above and parallel to a ground plane, the "slot" being formed by the air gap between the slot-ring and the ground plane. Such a slot antenna, when mounted horizontally, has an antenna response pattern similar to that of a vertical $\lambda_0/4$ antenna for a vertically polarised radio signal, but the frequency response is too narrow to be useful in many applications. For example, a slot antenna with a single slot-ring will have a frequency response with a bandwidth of about 3%. At 500 MHz, this would give a useful bandwidth from 493 MHz to 507 MHz, which is too narrow for many applications, such as cellular radio communication.

The document GB 1387679 recognises this problem, and proposes the use of a second parallel slot-ring with a different diameter. Since the diameter of the slot-ring is one parameter that defines the resonant frequency, this document suggests that two parallel slot-rings may be used to communicate at two different frequencies, each frequency being that for a slot-ring on its own. Because the frequencies of the slot-rings are far enough apart, the slot-rings do not interact strongly and are essentially uncoupled. This antenna arrangement of two slot radiators provides radio communication at two discrete frequencies, each having a narrow bandwidth.

Radio transmitters and receivers, or communication units, for satellite communication are becoming increasingly common. For example, the global positioning system (GPS) allows a hand-held instrument that receives satellite signals to determine the position of the instrument on the face of the earth to an accuracy within a few metres. Such satellite systems typically operate at frequencies around 1.5 GHz. Because the transmission is from space, the antennas for these systems have an antenna response

pattern which is usually omnidirectional in the azimuthal plane and omnidirectional ideally over a half-sphere centered about the zenith.

Such an antenna response pattern cannot be obtained from a $\lambda_0/4$ vertical antenna or a slot antenna, but may be obtained from a horizontal or inclined microstripline or "patch" antenna. A patch antenna has a conducting strip or patch, and is usually rectangular in outline with a length of each side L of about $\lambda_0/2$. The patch radiator is mounted above and parallel to, or slightly inclined to a ground plane. Other designs use a C-shaped patch, or even an elliptical patch. A basic description of rectangular patch antennas may be found in a book titled "Antennas" by John D. Kraus, published by McGraw-Hill Book Company, 1988, at pp 745-749. Descriptions of other types of radiator suitable for communication with satellites may be found in a book entitled "VHF and UHF Antennas" by R. A. Burberry, ISBN 0 86341 269 6, in particular a "slot dipole antenna" described on page 228 and a "crossed slot with backing cavity" on page 225.

One type of multiple band antenna unit for both terrestrial and satellite communication is described in patent application EP 0 590 955 A2. This antenna unit has a generally horizontal planar microstrip or patch radiator for satellite communication, surrounded in the same plane by a loop radiator and with a rod radiator extending perpendicularly through the patch radiator. All three radiators share a common ground plane. The loop radiator is broken at a point, and so has a different mode of operation from the slot antenna described above. The loop radiator is horizontally polarised and is therefore not well-adapted for efficient reception of generally vertically polarised signals; hence the need for the rod radiator. The loop is also a poor radiator in the

configuration shown, that is, near the ground plane, and is therefore not well-adapted for transmission.

As a result of the differences in required antenna response patterns, an antenna for combined satellite and terrestrial radio communication has not been made into a compact, low profile and efficient antenna unit.

It is an object of the present invention to provide a compact dual band antenna unit with both a low vertical profile and minimum lateral extent which may be used for satellite and terrestrial radio communication.

Accordingly, the present invention provides an antenna unit for radio communication with terrestrial and satellite communication units, the antenna unit comprising substantially planar conducting sections in close proximity, the sections defining:

a) at least one ground plane;

b) a first radiator with a first antenna response pattern, the first antenna response pattern extending substantially in an elevation plane for communication with a satellite communication unit; and

c) a second radiator with a second antenna response pattern for communication with a terrestrial communication unit,

characterised in that the second antenna response pattern is adapted for radio communication with electromagnetic radiation having a vertically oriented electric field, the second antenna response pattern extending substantially in an azimuthal plane.

A terrestrial communication unit may be any radio transmitter and/or receiver on earth, and similarly a satellite communication unit may be any radio transmitter

and/or receiver in space.

The term "radiator" as used herein means a part of an antenna which may receive and/or transmit radio signals.

The antenna response pattern is defined in a half-sphere centered on the antenna unit, so that the azimuthal and elevation planes pass through the antenna unit. The antenna response pattern may then be defined across 360° in the azimuthal plane and across 180° degrees in any elevation plane passing through the antenna unit.

The antenna unit may advantageously have a second antenna response pattern that is omnidirectional over most of the azimuthal plane, and is ideally omnidirectional over substantially the whole of the azimuthal plane.

The antenna unit may also advantageously have a first antenna response pattern that is omnidirectional over most of the elevation plane, and is ideally omnidirectional over substantially the whole of any such elevation plane so that the first antenna response extends across a half-sphere centered on the zenith.

The term omnidirectional when applied to an antenna ideally means an antenna with an antenna response pattern which is substantially equal in all directions. In fact, the actual performance of an antenna unit may deviate from this ideal equal antenna response pattern. For example, a finite or non-symmetrical ground plane may produce some ripple in the far field radiation pattern. In such non-ideal cases, the antenna pattern response is said to be omnidirectional to within a certain number of decibels. Communication systems are generally designed to accommodate any variations from an ideal omnidirectional antenna response pattern, and the term omnidirectional as

used herein includes such non-ideal cases.

Preferably, the first antenna pattern response is omnidirectional to within 6 dB. Also preferably, the second antenna pattern response is omnidirectional to within 6 dB.

In one preferred embodiment, the first radiator is a patch radiator operating in a patch mode, and the second radiator is a slot radiator operating in a slot mode. In another preferred embodiment, the first radiator is a patch radiator operating in a patch mode, and the second radiator is a bent folded monopole radiator operating in a folded monopole mode.

The antenna unit will for most applications need to respond to a range of frequencies within a frequency band, which for terrestrial signals may, for example, be one of the mobile radio bands at about 400 MHz, 900 MHz and 1.7 GHz. Therefore, it is advantageous if the second radiator of the antenna unit has an intrinsically broad operating bandwidth, for example a bent folded monopole may have at least a 20% bandwidth relative to a central operating frequency. If the second radiator operates in a slot mode, it may be formed from a number of sections that are designed to broaden the frequency response of the slot mode.

In order to minimise the vertical profile of the antenna unit, the second radiator may be arranged to be substantially coplanar with the first radiator.

In a preferred embodiment, the second radiator is arranged in the shape of a closed ring. In a preferred embodiment, the ring is a closed annulus and operates in a slot mode.

A single section of the second radiator in the shape of a ring and operating in a slot mode will have a relatively narrow bandwidth of operation of about 3%, which equates to a bandwidth of ± 15 MHz at 1 GHz. In contrast, mobile radio bands typically extend over 3 to 5 times this bandwidth. Therefore it is advantageous if the frequency response of the second radiator is broadened. This may conveniently be achieved by forming the second radiator antenna from a number of sections. For example, each section on its own may have an operating frequency separated by about 3% from another section. Such sections when placed in close proximity will have a response which overlaps and couples to broaden the response of the second radiator operating in a slot mode.

For example, the slot radiator may be formed from two parallel and adjacent annuli, both with different inner and outer radii and slot-ring widths and spaced apart by air, or alternatively by a low loss dielectric layer with a relative permittivity $\epsilon_R = 2$, then the frequency response of the antenna may be increased by a factor between about 1.5 and 2. Increasing the number of layers of parallel annuli will increase the broadening. The exact amount of broadening depends on a number of parameters, such as the sizes, shapes and relative lateral separations and spacing of the sections with respect to each other and to the ground plane, the dielectric constants of the spacing layers, and whether and at what points the sections are electrically connected together. If the sections are electrically insulated from one another they will still interact by parasitic coupling.

Parasitically coupled slot-rings provide the advantage of close control of matching of parameters and coupling. For example, planar sections of conducting material may be printed on thin dielectric substrates and sandwiched

together in a solid multilayer construction, with each section thereby held in secure relationship with and, if desired, electrically insulated from one another.

In another embodiment, these slot-rings may be concentric and coplanar annuli with different radii printed on one side of a single circuit board and centered about the same point. The sections may be electrically connected together at points. Alternatively, the slot-rings may be annuli with different circumferences, and centered at different points so that the outer edge of each annulus comes together and is electrically connected to the others at one point. In general, the ratio of the conductor width W of a slot-ring to the height H of that slot-ring above the ground plane governs the impedance of that slot-ring, and the W/H ratio may therefore be chosen such that each section provides equivalent electrical performance in terms of resonance characteristics.

In order to minimise the size of the antenna unit when the slot radiator is in the shape of a ring, the patch radiator may be inside the slot-ring. The feasibility of this arrangement depends on a number of factors which determine the sizes of the slot slot-ring and the diagonal extent of the patch, but in general this is possible when the frequency bands used by the patch radiator are at least as high as those used by the slot radiator.

The patch radiator may also be substantially coplanar with the slot radiator, or at least not extend significantly above the plane defined by the slot radiator. Then, when the patch radiator is inside the ring of the slot-ring radiator, the lateral extent and vertical thickness of the antenna unit are minimised making it easier to mount the antenna unit flush with the surface of a mobile unit such as a motor vehicle, or within a compact hand-held device

such as a mobile telephone or personal pager.

The first and second radiators may also advantageously share a common ground plane. The ground plane may optimally be arranged to be parallel and adjacent to both radiators. The greater the lateral extent of the ground plane, the greater the efficiency of the antenna unit, and hence the ground plane may also optimally extend beyond the edges of the radiators.

However, adequate performance may still be obtained if the ground plane extends no farther than the outer edges of the antenna unit, which may be the case where the permissible size of the antenna unit is limited, for example, in the case of a hand-held device.

If the volume of the antenna unit must be further minimised, then the ground plane for the slot radiator may be in the shape of a ring which may match the shape of the slot-ring. Some of the volume inside the inner diameter of the slot-rings may then be made available for other uses in the device package, although the efficiency of the slot radiator will be lower as a result.

When the size or diameter of the slot radiator and diagonal extent of the patch radiator are comparable, then the patch radiator may serve as a ground plane for the slot radiator, with the patch radiator having its own ground plane. Alternatively, both the patch radiator and its ground plane may interact with the slot radiator, with both the patch and its ground plane serving to some degree as ground planes for the slot radiator.

The extent of the bent folded monopole radiator transverse to the ground plane may be reduced if the folded monopole is bent to parallel the ground plane. The folded monopole

will generally have an elongate loop, and this loop may be folded to run in a plane which is either transverse or parallel to the ground plane.

The bent folded monopole will be in close proximity but in general be laterally spaced from the patch radiator.

All of these arrangements are made possible by the fact that the operation of one radiator does not greatly affect the operation of the other when the frequencies are well-separated. The first and second radiators do interact to some degree when placed in close proximity, and the antenna resonances of the different radiators of the antenna unit have to be optimised as a whole, but the antenna far field response patterns remain independent, making it possible here to combine different antenna radiators in a compact and low profile arrangement.

The term "close proximity" as use herein generally means a proximity resulting from an attempt to reduce or minimise the physical size of the antenna unit. Such a close proximity between the sections will generally cause an interaction between the sections, such as frequency response broadening or frequency response shifting.

In general, it is preferred if the first and second radiators are electrically connected to each other. This allows just one radio frequency feeder to be run to the antenna unit. In this case the first and second radiators must be designed to be impedance matched to each other to minimise standing waves and maximise power transfer.

Alternatively, the first and second radiators may not be directly connected to the patch radiator, and each may have its own transmission line. However, the transmission lines may still be joined at a point and provided with,

for example, quarter-wave stubs to prevent significant levels of transmission signals destined for one radiator from reaching the other radiator.

In many applications, it will be preferable if the antenna unit is mounted in a housing to provide protection. The housing will then comprise a cover section which is substantially transparent at the frequencies used by the antenna unit for radio communication. The cover may be formed from a suitable plastics material such as ABS, and may additionally be coloured to provide a good cosmetic match with any surrounding surfaces. Any frequency shift resulting from the cover dielectric may be taken into account at the antenna design stage.

The antenna unit according to the invention may be used on a mobile unit. Therefore, the invention also provides a mobile unit comprising an antenna unit for radio communication with terrestrial and satellite communication units, in which the antenna unit is according to the invention as described above. Examples of a mobile units include a motor vehicle, a motor boat or an aircraft, and also a hand-held personal telephone or pager.

An antenna unit may advantageously be mounted so that its housing or cover is substantially flush with the surrounding surface of the mobile unit. For example, a motor vehicle body shell may have a recess or aperture provided in a roof panel, or hood or trunk lid, which receives the antenna unit housing. Alternatively, the antenna unit may stand proud of the surface.

If the mobile unit has metal body parts, a section of those parts may form a ground plane. For example, the mobile unit may be a motor vehicle with a steel body shell. Such a body shell normally comprises a roof

section which is substantially horizontal and at the highest point of the vehicle. The antenna unit may then conveniently be mounted on the roof section, which may be provided with a recess so that the antenna unit can be mounted flush, and use the conducting skin of the motor vehicle as a ground plane.

The invention will now be described further by way of example with reference to the accompanying drawings, in which:

Figure 1 is a top view of a first antenna unit according to the invention, showing a slot radiator with two annular slot-rings, and a patch radiator centered within the slot radiator, and with both antenna radiators having the same ground plane;

Figure 2 is a side view in cross section taken along line II-II of the first antenna unit of Figure 1;

Figure 3 is a top view of a second antenna unit according to the invention, showing a slot radiator in the form of a wire suspended above a patch radiator and using the patch radiator as a partial ground plane, and with a main ground plane for both the patch and slot radiators;

Figure 4 is a side view in cross section taken along line IV-IV of the second antenna of Figure 3;

Figure 5 is a top view of a third antenna unit according to the invention, showing a slot radiator in the form of one annulus and a patch radiator above the slot radiator, and with both radiators having a common feed point and ground plane;

Figure 6 is a side view in cross section taken along line VI-VI of the third antenna unit as shown in Figure 5.

Figure 7 is a side view of a known folded monopole radiator;

Figure 8 is an isometric view of a fourth antenna unit according to the invention, showing a first bent folded monopole radiator and a patch radiator beside the monopole, with both radiators having separate feed points and a common ground plane;

Figure 9 is a side view of the first bent folded monopole of Figure 8, taken along line IX-IX; and

Figure 10 is an isometric view of a fifth antenna unit according to the invention, showing a second bent folded monopole radiator and a patch radiator beside the monopole, with both radiators having separate feed points and a common ground plane.

The drawings show orthogonal axes x,y and z. Axes x and y are in the azimuthal plane, and the elevation plane is any plane parallel to the z axis, which defines vertical. On earth, the azimuthal plane will normally be parallel with the horizon. If the antenna unit is used in space the azimuthal plane may have any orientation according to the application of the antenna unit.

Referring first to Figures 1 and 2, the first antenna unit 1 consists of a slot radiator 2 and a square patch radiator 3. Both radiators share a common horizontal ground plane 4, which extends beyond the edges of the slot radiator 2 so increasing the efficiency of the slot mode.

The slot radiator 2 is formed from two parallel annular conducting slot-rings, namely an upper slot-ring 5 and a lower slot-ring 6, on opposite sides of a printed circuit board 7 which is on the top side of the antenna unit 1. The patch radiator 3 is formed from conducting material on the upper side of the circuit board 7. Similarly, the ground plane 4 is formed from a conducting layer on the lower surface of a lower printed circuit board 8 which is on the bottom side of the antenna unit 1.

The upper and lower circuit boards are spaced apart and held in a solid construction by dielectric layers, with one layer 9 between the slot radiator 2 and ground plane 4, and the other layer 10 between the patch radiator 3 and the ground plane 4. The two slot-rings 5,6 of the slot radiator are electrically connected together by a VIA at a ground point 11 and from this point connected perpendicularly through the slot dielectric 9 to the ground plane 4.

The slot-rings also have a common slot feed point 12, which is in this example spaced optimally at a circumference of about 5° of free-space wavelength from the ground point 11.

The patch radiator 3 has a patch feed point 13 which is midway between two parallel edges and one-third the way in from another edge.

Each feed point 12,13 is wired to a core conductor 14,15 of a shielded coaxial cable 16,17. Each conductor passes through a bore 18,19 which forms a channel from the slot or patch radiator through the dielectric layer 9,10, lower circuit board 8 and ground plane 4. The shielding 20,21 of each cable is grounded to the ground plane next to each bore so as to be nearly directly below the feed point

12,13.

The two coaxial cables 16,17 may be joined into a single cable, and isolation between the signals may be achieved in a conventional manner by the use of quarter wave stubs and/or by PIN diode protection.

It is often the case that manufacturing tolerances, or the need to mount an antenna unit 1 with different ground planes 4, will result in different antenna units having a slot radiator 2 with slightly different resonant frequencies. Such variations can be accommodated if the antenna unit comprises a tuning capacitor 22 at a point on the slot-ring directly opposite the ground point 11. The exact location of the capacitor on the ring has a bearing on the sensitivity of the resonant frequency of the ring to the value of capacitance. If the connection of the capacitance is offset from the directly opposite ground post position, then less frequency change is induced for a given capacitance. This is a useful feature in a manufactured item.

This capacitor can take one of several forms, and as shown in Figures 1 and 2 is a rectangular conducting section on the upper circuit board 7 connected by a narrow neck 23 to the outer edge of the upper slot-ring 5. The area of the capacitor is trimmed along an edge, for example by a laser, and as indicated by a dashed line 24 in order to tune the resonant frequency of the slot-ring 5 to the desired value.

Another design of variable capacitor, not shown in the drawings, is a grounded conducting plate between the slot radiator and the ground plane that can be moved to adjust the separation between the plate and slot radiator. A further way of varying the capacitance between these

layers would be to insert or withdraw a section of dielectric called a dielectric puck.

The capacitance can also be changed by means of electronic switching, that is, by turning on or off PIN diodes connected to capacitor sections. This method of changing the resonance frequency and/or the matching, is applicable on transmit and receive. For low power transmit and for receive it is also possible to tune the resonance of the antenna by means of the capacitance provided by varying the bias voltage applied to reverse biased capacitance diodes.

The slot-rings 5,6 of the slot radiator 2 typically have a circumference of up to $\lambda_0/2$, where λ_0 is the free-space wavelength of the radio wave. The impedance of the slot radiator depends on a number of factors such as the width of the conductors forming the rings or slot-rings and their heights above the ground plane 4, taking into account also any dielectric 9,10 between the slot-ring and the ground plane. In the embodiment shown in Figures 1 and 2, the circumference of each slot-ring is about 163° of free-space wavelength. At 1 GHz, the circumference is then 136 mm (diameter 43.2 mm). If the slot dielectric 9 were replaced by air, the spacing of the slot-ring above the ground plane would optimally be about 8°, which at 1 GHz is 6.7 mm. For a slot dielectric formed from alumina with a relative permittivity $\epsilon_R = 10$, the spacing would be about 2.5°, or 2.1 mm.

The spacing between the patch 3 and the ground plane 4 may be somewhat less than for the slot radiator for a dielectric with a given relative permittivity. When the patch radiator is not inclined to the ground plane, this spacing is typically $t = \lambda_0/100$, or 3.6°. The patch has a length $L = \lambda_0/(2(\epsilon_R)^{½})$ where ϵ_R is the relative

dielectric constant of the patch dielectric 10, which may have values typically which range upwards from 2. It is generally preferred have a higher dielectric constant in order to reduce the size of the patch radiator. In Figures 1 and 2, the width W of the patch is the dimension between the two edges within which the feed point is centered, and the length L is the dimension at right angles to this. The width W of the patch may be conveniently be chosen to be about the same as, or just less than, the length L.

With a dielectric constant of 10 and at a frequency of 1 GHz, the size of a square patch is therefore 47.4 mm along a side, and 67.1 mm diagonally. This is somewhat larger than the 43.2 mm diameter of the 163° circumference slot-ring described above at the same frequency. At an operating frequency of 1.7 GHz the square patch would have a diagonal dimension of 39.5 mm, and could then fit within the 1 GHz slot-ring.

The optimum spacing of the slot and patch radiators 2,3 can also be adjusted by selecting appropriate dielectric layers 9,10. This permits the slot and patch radiators to be formed on the same circuit board substrate 7.

A patch radiator 3 as described has a radiation pattern which is broad and directional, typically at least ¼ of the full solid angle, or π sr. When the patch is horizontal and parallel to the ground plane 4, this radiation pattern is a cone approaching a half-sphere centered on the zenith.

There are a number of methods by which the frequency response of the patch radiator 3 may be broadened, for example by inclining the patch with respect to the ground plane.

The effect on the slot radiator 2 of the two parallel and electrically connected slot-rings 5,6 is to broaden the frequency response of the slot radiator by a factor of about 1.5 to 2. More parallel slot-rings may be added to broaden further the frequency response. The slot-rings may conveniently be formed on the surfaces of circuit boards in a multilayer laminated construction. The inner and outer diameters and widths of the slot-rings will not be the same, but will generally decrease for each lower slot-ring in the construction. The resonant frequency for each slot-ring on its own is chosen to be within 3% of another slot-ring, so that each slot-ring in the multilayer slot-ring structure is resonantly coupled to broaden the frequency response of the slot radiator as a whole.

Figures 3 and 4 show a second antenna unit 31 which consists of a slot radiator 32 in the form of a single circular slot-ring of wire, mounted above a square patch radiator 34. The patch radiator is formed from a conducting layer on a printed circuit board 33 which is mounted on a dielectric spacer layer 36 above a ground plane 35 formed from sheet metal which extends beyond the outer edge of the patch radiator 34.

The slot radiator 32 uses the topmost conducting surface of the patch radiator 34 as a partial ground plane, with the ground plane 35 serving as a main ground plane for the slot radiator 32.

The patch radiator 34 has a similar construction to the patch radiator 3 described for Figures 1 and 2. However, the slot radiator 32 is quite different, being formed from a ring of wire with circular cross section. This construction maintains a reasonable efficiency for the slot radiator 32, while allowing it to be placed above the

patch radiator 34.

Such a wire slot radiator 32 would have a relatively narrow bandwidth, which could be broadened by the addition of other parallel and/or concentric rings of wire or printed conductor, suspended by low loss substrate.

The patch radiator 34 is fed by a shielded coaxial cable 41 with a core conductor from this cable electrically connected to the patch 34 at a patch feed point 40, in a like manner to the patch radiator 3 of Figures 1 and 2. However, this cable 41 serves as a single unbalanced coaxial feed for both radiators of the antenna unit 31 as will be clear from the following description.

The slot-ring is suspended above the patch radiator 34 by an insulating post 38 and at the opposite side of the slot-ring by a conducting post 37 which extends through an aperture 43 in the patch radiator 34 to the ground plane 35. The conducting post 37 provides a ground point on the slot-ring by electrically connecting the slot radiator to the ground plane 35 at that point, and the insulating post 38 may comprise one of the forms of capacitance adjustment described above.

The aperture 43 is made small compared with the wavelength of operation of both the patch and slot radiators, and so evanescent modes generated by the hole in the patch conductor are negligible, and therefore so will be the effect on the operation and radiation efficiency of the patch.

A wire 42 is electrically connected to the upper surface of the patch radiator 34 at the patch feed point 40, and extends to the wire slot-ring of the patch radiator where it is electrically connected at the slot feed point 39.

A single feed line may therefore serve both radiators of the antenna unit 31.

In a variant of the embodiment shown in Figures 3 and 4, the slot-ring 32 may be offset from the centre of the patch radiator 34 in order to place the slot feed point 39 directly above the patch feed point 40.

The parasitic capacitance introduced by the introduction of the patch above or below the slot-ring serves to alter the feed point on the slot-ring. Since the feed point of the slot-ring is designed to be fed by a low impedance TEM (transverse electric and magnetic) unbalanced transmission line with, for example, an impedance of 50 Ω, the effects of the capacitance introduced by the patch area above the ground plane is small and it is readily compensated for in the matching.

In one prototype, a Gamma matching section was used to feed and match the slot-ring. Other feed and matching arrangements are equally applicable. For example, an H-field ring coupling to the slot-ring will work well.

A common feeder arrangement is also possible with a planar design using conducting sections on multilayer printed circuit boards. In another embodiment of the invention, illustrated in Figures 5 and 6, an antenna unit 51 has an square patch radiator 52 mounted above an annular slot radiator 53.

The radiators 52,53 are made from conducting sections on either side of a printed circuit board 56. The two radiators are not centered with respect to each other, but are aligned so that the feed points 54 of both radiators are immediately adjacent, with a short signal VIA 57 electrically connecting the feed points to each other.

The radiators will occupy more space, but this embodiment provides a more efficient electrical arrangement.

When a common feed point is used, it will generally be desirable to use signal combining/decombining networks (not shown) so that both radiators may be used simultaneously. Alternatively, PIN diode switches or relays (not shown) may be used to switch between radiators.

In most applications, the slot may comprise more than one slot-ring, as described above, in order to broaden the bandwidth of the slot mode. Such additional slot-rings would be formed on additional surfaces of a multilayer circuit board, with all feed points adjacent and connected through by signal VIAs.

The feed point 54 on the patch 52 is offset in a manner different from previously described embodiments, with the feed point about one-third the way in from two adjacent edges. The precise patch feed point in any particular application will depend on the resonant mode employed in the patch.

A dielectric layer 58 separates the patch and slot radiators from the ground plane 59. The slot radiator 53 has a ground point 55, which is connected through to the ground plane by a ground VIA 60.

A single unbalanced coaxial feeder cable 61 has a core conductor 62 which passes through a bore 63 in the dielectric layer 58 to make electrical contact with the feed points 54.

The patch operation is largely unaffected by the slot-ring. The slot-ring now has the capacitance produced by

the patch connected across the feed point. The position of the feed point is adjusted to conjugately match this capacitance in a manner familiar to those experienced in the art.

There exists another way in which the slot radiator according to the invention may be used, and that is in a $3\lambda_0/2$ circumferential mode, which operates at three times the fundamental frequency. A $\lambda_0/2$ slot mode and a $3\lambda_0/2$ circumferential mode may be excited together and result in a far-field radiation pattern of mixed polarisation, that can be used for both terrestrial and satellite communication. In this instance, the slot radiator may act as both the first radiator (eg at 1575 MHz) and the second radiator (eg at 525 MHz).

This higher frequency mode has a good return loss and more than 8% operating bandwidth when fed with the same feed arrangement as the fundamental $\lambda_0/2$ slot mode. In other words, the $3\lambda_0/2$ circumferential mode has a low feed impedance.

The same arrangement of parallel slot-rings described above to broadband the $\lambda_0/2$ slot mode will also increase the bandwidth of the $3\lambda_0/2$ circumferential mode. Thus, if the fundamental frequency of operation, and three times this frequency are required for simultaneous operation, an antenna unit with a slot-ring mode is an attractive option.

The radiation pattern of the $3\lambda_0/2$ circumferential mode has lobes in the azimuthal and elevation planes, with one of the azimuthal lobes centered on the feed point. The radiation pattern is also broad in the elevation plane compared with the antenna response of the $\lambda_0/2$ slot mode of operation.

Because the wavelength of the $3\lambda_0/2$ circumferential mode is one-third of the $\lambda_0/2$ slot mode, the W/H ratio is effectively one-third that of the $\lambda_0/2$ slot mode, and this has the effect of broadening the bandwidth of the frequency response.

The degree of azimuthal lobing does not have an effect greater than about 6 dB on the antenna response, and this sensitivity variation may be further reduced with a reduced extent ground plane and/or a shaped ground plane. Therefore, the radiation pattern characteristics of an antenna unit with a slot-ring operating at both fundamental and $3\lambda_0/2$ circumferential modes provides usable terrestrial and earth-orbiting satellite coverage, with the frequency for satellite communication three times that for terrestrial communication. In the case of such $3\lambda_0/2$ operation, the patch radiator may be omitted or included. In the latter case, both the $3\lambda_0/2$ slot mode and the patch mode, if they are resonant at the same frequency, will both contribute to the far field radiation response, and may together provide some useful diversity in terms of sensitivity to radio signals with different polarisations. When the $3\lambda_0/2$ circumferential mode and the patch mode are resonant at different frequencies, then both sections operate essentially independently.

One type of known antenna having a vertically oriented electric field, and with an antenna response pattern extending substantially in an azimuthal plane, is illustrated in Figure 7, which shows a folded monopole radiator 71. The folded monopole radiator is in the shape of an elongate rectangular loop 70 extending transversely to a ground plane 72. One end 73 of the loop passes through an aperture 74 in the ground plane to present an unbalanced feed point, which may be connected to an unbalanced coaxial feed cable as described above. The

other end 75 of the loop terminates at a solder joint 76 on the ground plane 72.

The typical length of a folded monopole radiator is between $0.25\lambda_0$ and $0.375\lambda_0$. The physical dimensions of the monopole loop can be reduced by a factor of $1/(\epsilon_R)^{1/2}$, as described above, by embedding the monopole loop in a suitable low-loss dielectric material. Whilst the folded monopole radiator 71 is an efficient antenna, it has the disadvantage of extending substantially away from the plane of the ground plane 72, even with a size reduction by choice of a suitable dielectric.

Figure 8 shows a fourth embodiment of an antenna unit 81, having a patch radiator 80, for example a patch radiator suitable for GPS communication at 1575 MHz, and beside this a first bent folded monopole radiator 82, both above a common ground plane 83. The two radiators 80,82 are in close proximity such that their self-resonant frequencies may be lower than if either radiator were isolated from the other.

Typical dimensions of a typical first bent folded monopole 82 are shown in more detail in Figure 9. The bent folded monopole 82 has a height above the ground plane which is a function of the dielectric loading employed.

As with the conventional folded monopole 71, the first bent folded monopole 82 at one end extends through an aperture 86 in the ground plane 83 to an unbalanced feed point 84, and at the other end is soldered to the ground plane 83 at a ground point 85. From the feed point 84, the bent folded monopole extends transversely to the ground plane by typically $0.06\lambda_0$, and then is bent at right angles to run parallel to the ground plane along an upper leg 87 for a distance of typically $0.142\lambda_0$, before

being folded back underneath the upper leg 87, and finally through a lower leg 89 to the ground point 85. The first bent folded monopole 82 is therefore folded in a plane transverse to the ground plane.

Despite the asymmetric shape of the first bent folded monopole, the far field radiation pattern of this radiator is remarkably similar to that of the conventional folded monopole described above, being substantially omnidirectional over the azimuthal plane, and with an electric field having substantial components transverse to the azimuthal plane.

The dimensions of the first bent folded monopole transverse and parallel to the ground plane can be reduced by a factor of up to $1/(\epsilon_R)^{½}$, as described above, by spacing the monopole loop from the ground plane with a suitable dielectric material or by embedding the monopole loop entirely or partially in such a dielectric.

One difference between the straight and bent folded monopole is that the bent folded monopole has a broader frequency response, which may be advantageous in many applications needing a broader bandwidth of operation. Because of its bandwidth, the bent folded monopole is also less sensitive to proximity couplings from nearby objects, and is therefore less prone to detuning effects.

Another difference is that whilst the impedance of the straight folded monopole is theoretically 200 Ω, the impedance of the bent folded monopole is in general different from this. The actual impedance will depend on the ratio of the dimensions of the sections parallel and transverse to the ground plane, and the height of upper leg 87 above the ground plane. These parameters may be selected to adjust and match the impedance. This height

is called the electrical height which will be reduced if the space is filled with a dielectric material. The dimensions used to fabricate the antenna have a secondary effect on the impedance, operating bandwidth and efficiency. From this it will be appreciated that many different variants of bent folded monopole may be used to effect the invention, and that the shapes selected do not need to be restricted to rectangular folded sections as illustrated.

The bent folded monopole 82 is positioned laterally adjacent the patch radiator 80, which is similar to those described above, with a feed point 88 spaced by a dielectric layer 90 parallel and above the ground plane 83.

A fifth embodiment of an antenna unit 100 is illustrated in Figure 10. Here a patch radiator 101, similar to that described above, is laterally adjacent to a second bent folded monopole 102 that is folded with two upper legs 107,109 in a plane parallel to a common ground plane 103. The dimensions of the second bent folded monopole are similar to those of the first bent folded monopole, and can be reduced with the use of a dielectric.

Again, despite the asymmetric shape of this second bent folded monopole, the far field radiation pattern of this radiator is remarkably similar to that of the conventional straight folded monopole and first bent folded monopole described above. The shape and dimensions of the ground plane may be used to modify the far field pattern.

The bent folded monopoles described above have been illustrated for clarity as unsupported conductors. In practice, the monopoles could be supported either by a surrounding dielectric material or by printed circuit

boards. The bent folded monopoles, of course, have conductors which extend transversely (these may, for example, be VIAs between or through circuit boards) to the ground plane and patch radiator, but are composed mainly of planar sections, that is sections of conductor arranged in planes parallel to the ground plane in order to minimise the height of the bent folded monopole radiators above the ground plane.

The feed points to the bent folded monopole and the patch radiators may also be electrically connected at a common feed point, with appropriate impedance matching, as described above for the slot and patch radiators.

Gaps between the radiators' planar sections and the common ground plane may be filled with suitable dielectric materials or just with air ($\epsilon_R=1$) in order to adjust the physical spacings so that the radiators' planar sections, for example the upper leg 87 and patch 80, are substantially coplanar.

The bent folded monopole may be placed closer to the patch radiator than illustrated, or folded over the patch radiator. This would, however, increase the degree of interaction between the two radiators, which would have to be compensated for in the design of the radiator sections.

The various embodiments of the antenna unit according to the invention may be optimised for a range of applications for the provision of dual band operation for reception and/or transmission for both terrestrial and earth-orbiting satellite radio communication. In particular, the size of the antenna unit may be minimised, both in terms of lateral extent and vertical profile, allowing the antenna unit to be used with a variety of hand-held

devices or mobile units, and the antenna response pattern may be designed to optimise radio communication with a range of satellite or terrestrial communication units.

Claims

1. An antenna unit for radio communication with terrestrial and satellite communication units, the antenna unit (1,31,51,81,101) comprising substantially planar conducting sections in close proximity, the sections defining:

a) at least one ground plane (4,34,35,59,83,103);

b) a first radiator (3,34,52,80,100) with a first antenna response pattern, the first antenna response pattern extending substantially in an elevation plane for communication with a satellite communication unit; and

c) a second radiator (2,32,53,82,102) with a second antenna response pattern for communication with a terrestrial communication unit,

characterised in that the second antenna response pattern is adapted for radio communication with electromagnetic radiation having a vertically oriented electric field, the second antenna response pattern extending substantially in an azimuthal plane.

2. An antenna unit according to Claim 1, in which the second antenna response pattern is omnidirectional over most of the azimuthal plane.

3. An antenna unit according to Claim 1 or Claim 2, in which the first antenna response pattern is omnidirectional over most of the elevation plane.

4. An antenna unit according to Claim 2 or Claim 3, in which, the second antenna response pattern is omnidirectional to within 6 dB.

5. An antenna unit according to any of Claims 2 to 4, in which the first antenna response pattern is

omnidirectional to within 6 dB.

6. An antenna unit according to any preceding claim, in which the first radiator is a patch radiator (3,34,52,80, 100).

7. An antenna unit according to any preceding claim, in which the second radiator is a slot radiator (2,32,53) operating in a slot mode.

8. An antenna unit according to any Claim 7, in which the second radiator (2,82,102) is formed from a number of sections (5,6 or 87,89 or 107,109) to broaden the frequency response of the slot mode.

9. An antenna unit according to any preceding claim, in which the second radiator (82,102) is arranged in the shape of a loop (82,102).

10. An antenna unit according to any preceding claim, in which the second radiator (2,32,53) is arranged in the shape of a ring (5,6,32,53).

11. An antenna unit according to Claim 10, in which the first radiator (3) is inside the ring (5,6).

12. An antenna unit according to any one of Claims 1 to 6 in which the second radiator is a bent folded monopole (82,102).

13. An antenna unit according to Claim 12, in which the bent folded monopole (82) is bent in a plane transverse to the ground plane (83).

14. An antenna unit according to Claim 12 or Claim 13, in which the bent folded monopole (82,102) is laterally

spaced from the first radiator (80,100).

15. An antenna unit according to any preceding claim, in which the first radiator (3,52,80,100) is substantially coplanar with the second radiator (2,53,82,102).

16. An antenna unit according to any preceding claim, in which the first radiator (34,52) and second radiator (32,53) are electrically connected to each other and are impedance matched to each other.

17. An antenna unit according to any preceding claim, in which the first radiator (3,34,52,80,100) and second radiator (2,32,53,82,102) share a common ground plane (4,35,59,83,103).

18. An antenna unit according to any preceding claim, in which the antenna unit (1,31,51,81,101) is mounted in a housing, and the housing comprises a cover section which is substantially transparent at the frequencies used by the first (3,34,52,80,100) and second (2,32,53,82,102) radiators for radio communication.

19. A mobile unit comprising an antenna unit (1,31,51,81,101) for radio communication with terrestrial and satellite communication units, in which the antenna unit is as claimed in any one of Claims 1 to 17.

20. A mobile unit according to Claim 19 when appendant to Claim 17, in which the mobile unit has a surface with recess therein adapted to receive the antenna unit (1,31,51,81,101), and the cover section is adapted to be flush with the surface surrounding the recess.

21. A mobile unit according to Claim 19 or Claim 20, in which the mobile unit has a conducting skin which forms

a ground plane for the antenna unit (1,31,51,81,101).

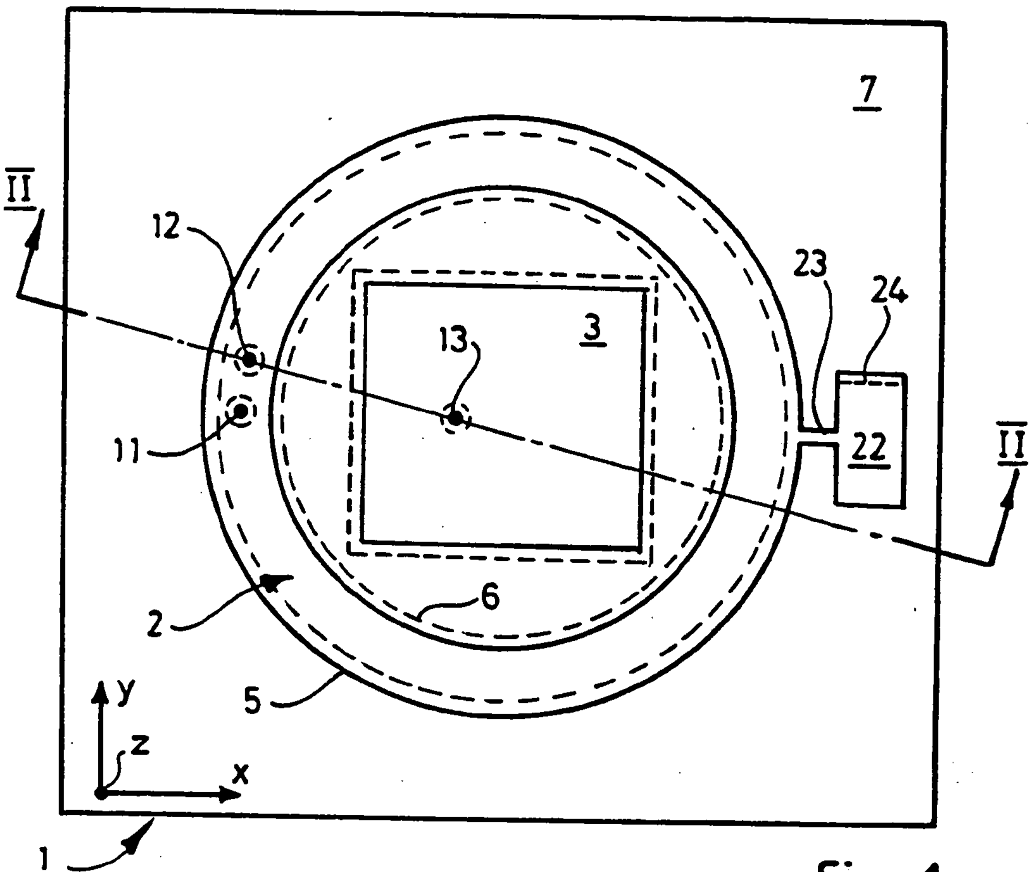
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Fig. 1

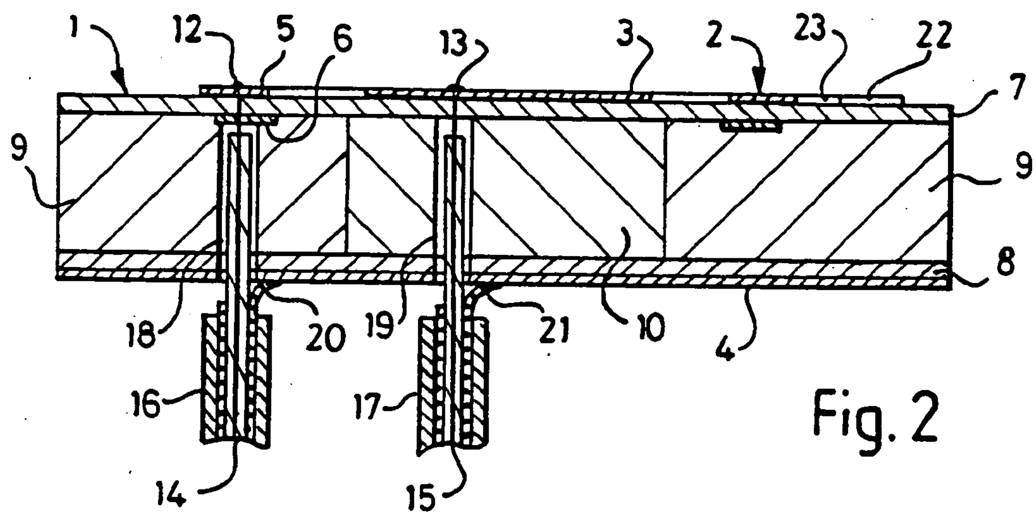
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Fig. 2

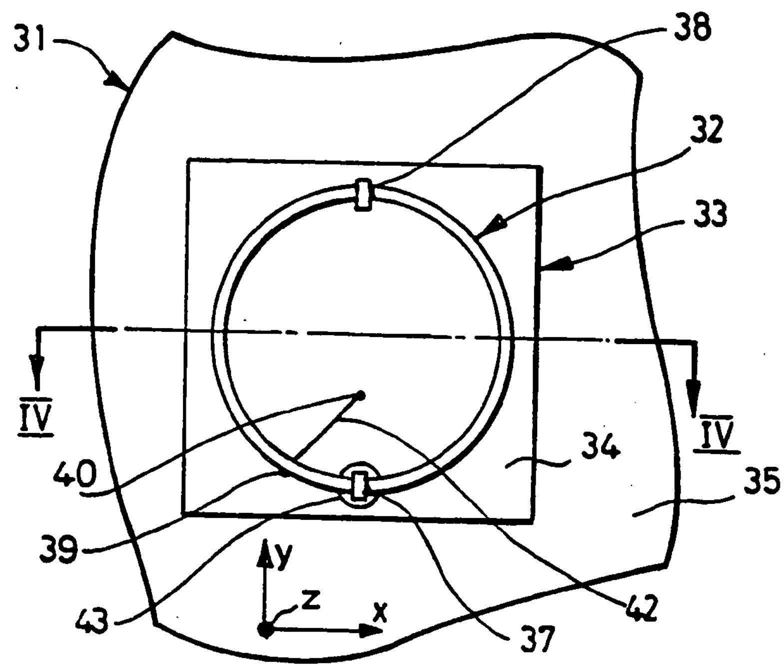

Fig. 3

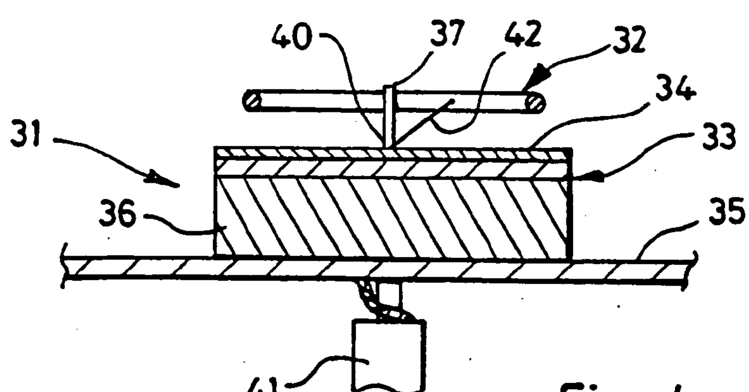

Fig 4

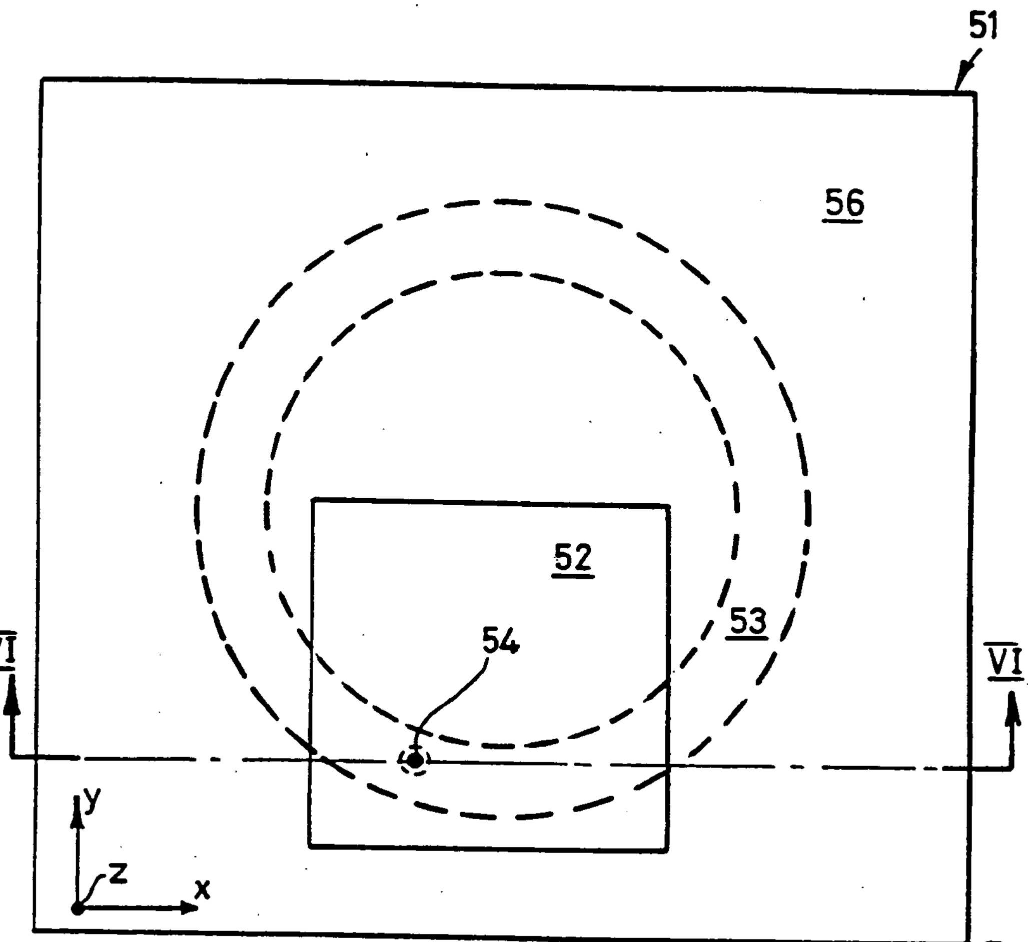

Fig. 5

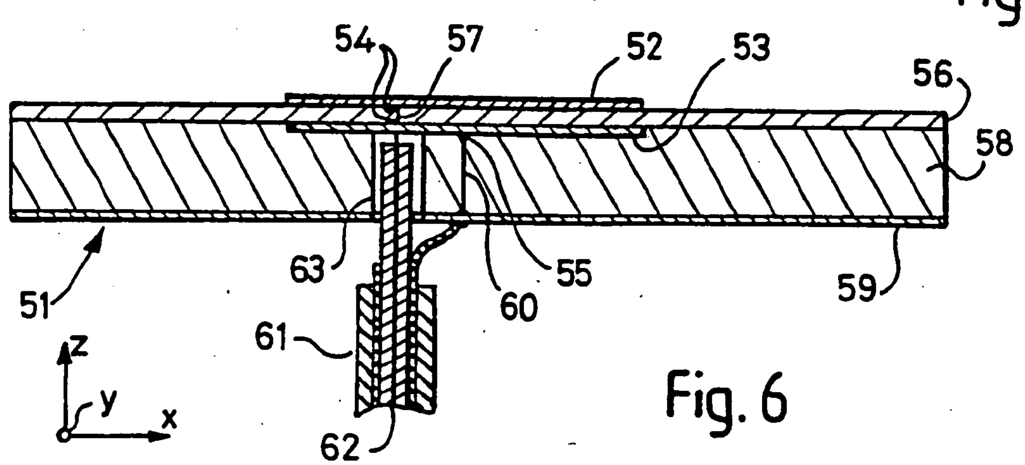

Fig. 6

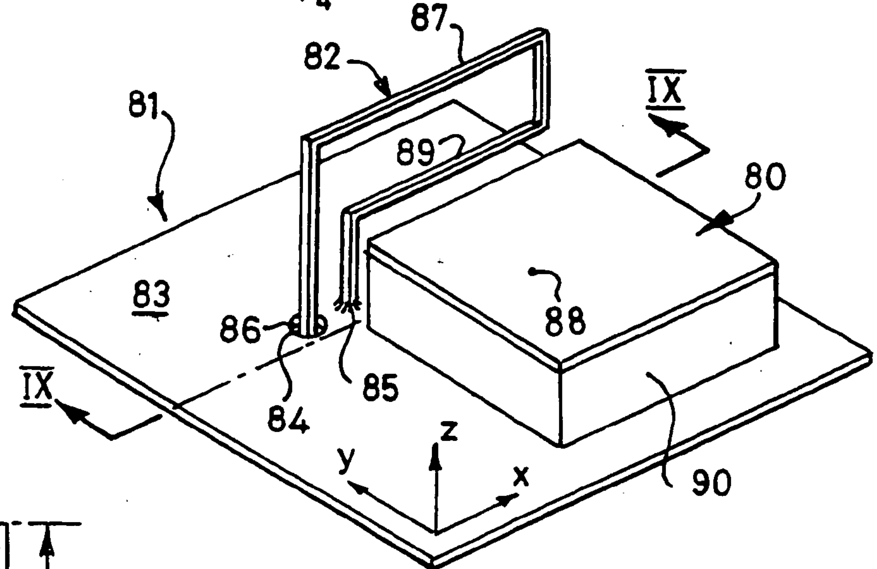

Fig. 8

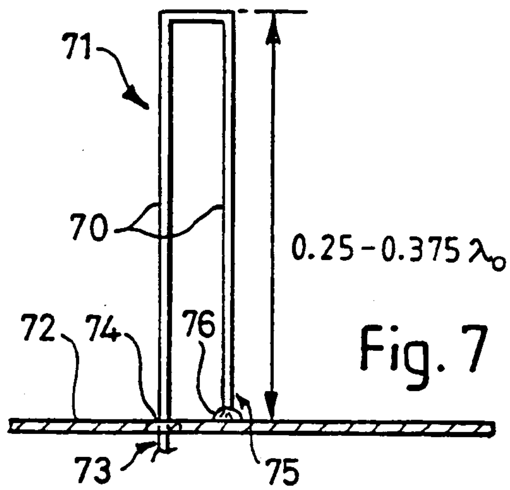

Fig. 7

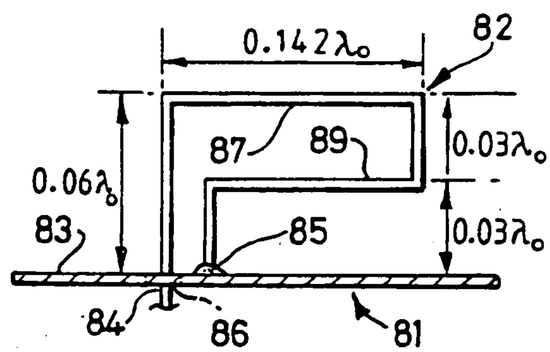

Fig. 9

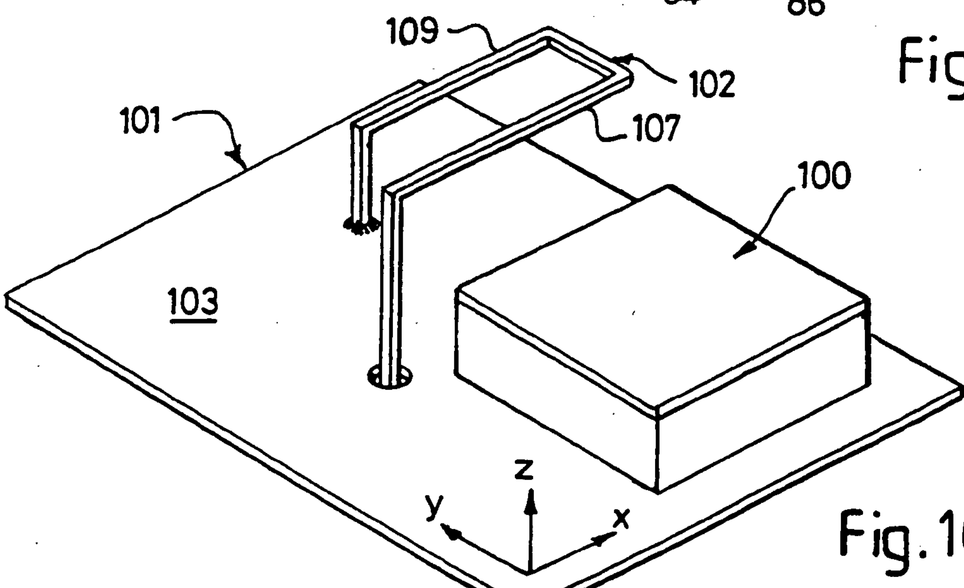

Fig. 10

INTERNATIONAL SEARCH REPORT

Inte onal Application No
PCT/GB 96/01041

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01Q21/28 H01Q1/32

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE,U,94 14 817 (WILHELM SIHN JUN.) 3 November 1994 see page 2, last paragraph - page 6; claims 1-9; figure ---	1-7,10, 11,19-21
X	FUNKSCHAU, vol. 67, no. 2, 5 January 1995, MUNCHEN DE, pages 60-62, XP000495360 BASHIR ET AL.: "Flache Kombiantenne für GSM und GPS" see the whole document ---	1-7,10, 11,19-21

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

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Date of the actual completion of the international search	Date of mailing of the international search report
14 August 1996	- 3. 09. 96

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Angrabeit, F

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Int. onal Application No
PCT/GB 96/01041

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	40TH IEEE VEHICULAR TECHNOLOGY CONFERENCE, 6 - 9 May 1990, ORLANDO,FLORIDA, pages 19-23, XP000203778 BADENES ET AL.: "A MULTIPUROSE FLUSH-MOUNTED ANTENNA SYSTEM FOR SATELLITE-LAND MOBILE COMMUNICATIONS AND POSITIONING" see the whole document	1-21
P,A	DE,U,295 06 693 (FUBA) 29 June 1995 see page 3, last paragraph - page 6; claims 1-6; figures 1-5	1-21
A	US,A,5 402 134 (MILLER ET AL.) 28 March 1995 see column 3, line 5 - line 18; claims 1,5,18-21; figures 1-5	1-21
A	EP,A,0 444 679 (TOYOTA) 4 September 1991 see column 9, line 53 - column 14, line 54; figures 1-15	1,12-14

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte onal Application No
PCT/GB 96/01041

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE-U-9414817	03-11-94	NONE	
DE-U-29506693	29-06-95	NONE	
US-A-5402134	28-03-95	NONE	
EP-A-0444679	04-09-91	JP-A- 3253106 DE-D- 69118740 US-A- 5146232	12-11-91 23-05-96 08-09-92